

Detonation Wave Profile in PBX-9501

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A plastic-bonded explosive (PBX) is composed of explosive grains held together by a polymer binder. When compressed by a shock wave, the heterogeneities give rise to energy concentrations or local regions of high temperature known as hot spots. Hot spots are essential for initiation of a detonation wave in a PBX.

One explosive used in Lab applications is PBX-9501. Its main ingredient is the high-melting explosive (HMX). A pure crystal of HMX is very insensitive, i.e., hard to detonate. This property along with other detonation phenomenon, such as “shock desensitization,” led to the conjecture that hot spots also are needed to propagate a detonation wave. In fact, burn models used in hydro simulations — such as “Forest fire” or “ignition and growth” — are motivated by the hot spot concept.

With the temporal resolution of the VISAR (Velocity Interferometer System for Any Reflector) technique now on the order of 1 nanosecond (billionth of a second), experiments have been able to measure the velocity profile in the reaction zone of a propagating detonation wave. For PBX-9501, the experimental profile, shown in Fig. 1, has the form of a classical ZND (Zeldovich-von Neumann-Doering) detonation wave; lead shock followed by rapid decrease from the unreacted von Neumann spike state to the fully reacted Chapman-Jouguet detonation state. Moreover, the reaction zone width is a fraction of the grain size. In addition, related HMX-based explosives, PBX-9404 and EDC-37, have very similar reaction zone profiles, despite having different binders and different sensitivities to initiation. This

is contrary to the behavior expected for a propagating detonation wave when reaction is dominated by hot spots.

The experimental reaction zone profiles are in good agreement with 1-D simulations using realistic constitutive properties for PBX-9501 (equations of state of reactants and products) and a global Arrhenius reaction rate fit to time to ignition data over a wide range of temperatures. The experiments used two window materials; PMMA (better known as plexiglas) and LiF, which bracket the acoustic impedance of PBX-9501. The resolution of the VISAR is somewhat lower with the LiF window resulting in the peak or von Neumann spike being clipped. Other experiments with a 1-ns resolution do obtain peak value of particle velocity in agreement with the value expected from the impedance match of the lead shock in PBX-9501 into the window material; see Fig. 2 for the graphical solution in the (particle velocity, pressure) plane. Thus we can conclude that a steady detonation wave in PBX-9501 is propagated by the bulk chemical reaction from shock heating [1].

The experiments measured the profile for a planar detonation wave. In a rate stick, the detonation front is curved with the lead shock being weaker at the boundary. Due to the temperature sensitivity of the Arrhenius rate, the reaction zone width greatly increases as the lead shock strength decreases. As a consequence, near the boundary, reaction is dominated by hot spots. This change of reaction mechanism reconciles the sensitivity of failure diameter to the formulation of a PBX (binder and grain size) with the insensitivity of the planar reaction zone profile.

For more information contact Ralph Menikoff at rtm@lanl.gov.

[1] R. Menikoff, “Detonation Wave Profile in PBX-9501,” Los Alamos National Laboratory report LA-UR-05-1633 (March 2005).

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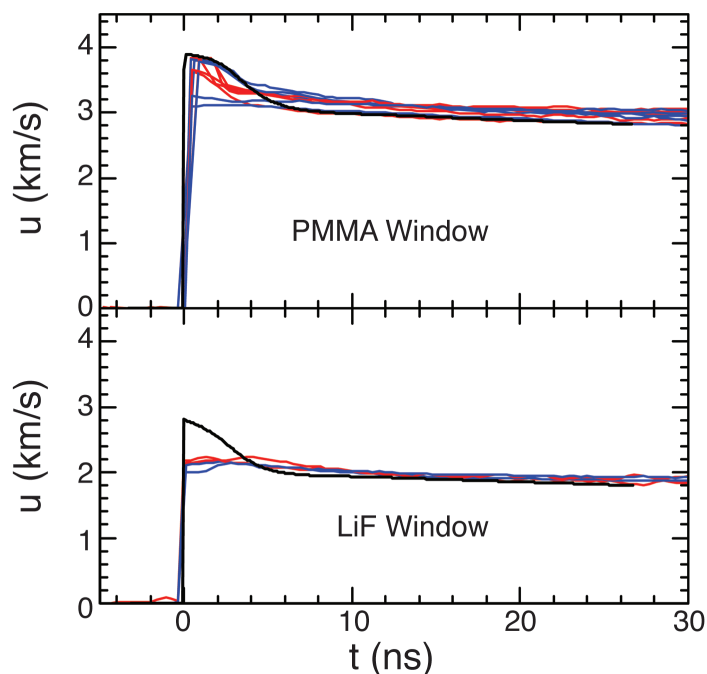


Fig. 1. Comparison with VISAR data from Gustavsen, Sheffield, and Alcon. Top figure is for PMMA window and bottom is for LiF window. Red and blue curves are experiments and black is simulations. VISAR used two laser beams with different fringe constants per experiment. Experiments varied drive pressure for initiation and the length of PBX sample.

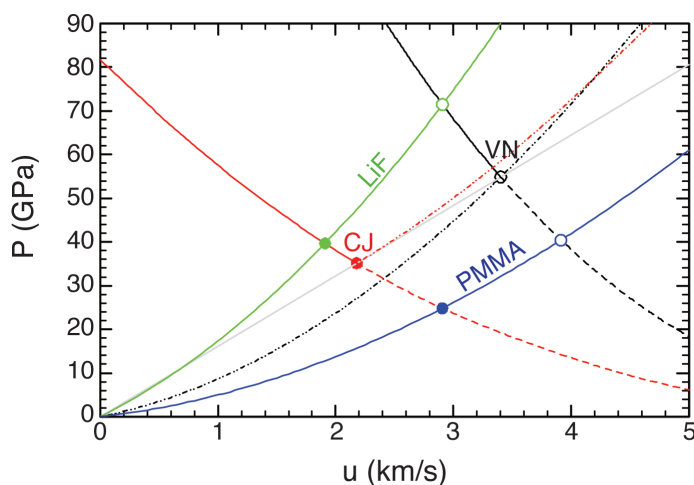


Fig. 2. Impedance match for detonation wave in PBX-9501 with window. Green and blue curves are Hugoniot loci for LiF and PMMA, respectively. Black and red curves are for reactants and products, respectively. Gray is Rayleigh line corresponding to CJ detonation velocity. Labels VN and CJ denote von Neumann spike and Chapman-Jouguet state, respectively. Open circles are match from VN spike and solid circles are match from CJ state.